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Cassini / Huygens science instruments

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ABSTRACT

The Cassini spacecraft will bring eighteen scientific instruments to Saturn. After it is inserted into Saturn orbit, it will separate into a Saturn Orbiter and an atmospheric probe, called Huygens, which will descend to the surface of Titan. The Orbiter will orbit the planet for four years, making close flybys of five satellites. Orbiter instruments are body-mounted; the spacecraft must be turned to point them toward objects of interest. The Orbiter carries twelve instruments. Optical instruments provide imagery and spectrometry. Radar supplies imaging, altimetry, and radiometry. Radio links contribute information about intervening material and gravity fields. Other instruments measure electromagnetic fields, plasma properties, and properties of dust particles. The Probe is spin-stabilized. It returns data via S-band link to the Orbiter. The Probe's six instruments include sensors to determine atmospheric physical properties and composition. Optical sensors will observe thermal balance and obtain images of Titan's atmosphere and surface. Doppler measurements between Probe and Orbiter will provide wind profiles. Surface sensors will measure impact acceleration, thermal and electrical properties, and, if the surface is liquid, density and refractive index.

Keywords: Cassini, Huygens, instruments, Saturn, Titan

1. INTRODUCTION

Cassini, a Saturn orbiter plus a Titan atmospheric probe, is a joint undertaking between the U.S. National Aeronautics and Space Agency (NASA), the European Space Agency (ESA), and the Italian Space Agency (ASI). NASA is supplying the Orbiter and ESA the Probe, which has been named Huygens. ASI is contributing several major assemblies. This paper surveys the science instruments of both the Orbiter and the Probe. Among accounts of pertinent previous work are Refs. 1-6.

2. SCIENCE OBJECTIVES

Major goals of the Cassini mission are to determine the elemental, molecular, isotopic and mineralogic compositions of Saturn, Titan, the smaller satellites, and the rings of the Saturnian system; to determine the physical, morphological, and geological nature of these objects; to determine the physical and chemical processes operating in the atmospheres of Saturn and Titan, and on the surfaces of the rings and satellites of the system; and to determine the physical and dynamical properties of Saturn's magnetosphere and its interactions with the rings and satellites.

3. MISSION

The Cassini spacecraft is to be launched in October 1997. It will use two gravity assists from Venus, one from Earth, and one from Jupiter to reach Saturn (Figure 3). Closest distance to the sun will be 0.68 A.U. Cassini will search for gravitational waves at opposition after the Jupiter flyby. Limited science measurements will be made during the two years prior to Saturn encounter

Cassini will reach Saturn in July 2004. The spacecraft will fly by the satellite Phoebe 19 days before closest approach, at a distance of about 50,000 km. The Saturn orbit insertion maneuver will take place just before periapsis at 1.3 Saturn radii (Figure 4). The initial orbit has a period of about 150 days and inclination of 17 deg (Figure 5). Another maneuver, at first apoapsis, will target the spacecraft for Titan flyby and raise its periapse to 8.2 Saturn radii.

In November 2004 the Huygens Probe will be spun up and released from the Orbiter. It will coast for 22 days after separation, then enter the Titan atmosphere at about 18 deg N latitude and 209 deg E longitude, on the daylight side The Probe will be aerodynamically decelerated to an altitude of about 190 km (Figure 7), at which heat shield and covers will be jettisoned and a parachute deployed. Parachute opening should be complete at 160 km altitude. Chemical analysis of the atmosphere and other science measurements will begin al this altitude. Descent from 190 km to the surface will take 2 to 2.5 hours. The Probe will impact the surface at 5 to 6 m/s. If it survives impact, science measurements may be obtained on the surface. Line of sight to the Orbiter for data relay will be available for at least 30 minutes after impact (Figure 7) '.

After Probe separation a small maneuver will deflect the Orbiter to fly by Titan at a minimum altitude of 1500 km, and delay its closest approach. This will keep the Orbiter and Probe in line-of-sight while the Probe descends through Titan's atmosphere, permitting Probe data to be transmitted to the Orbiter for storage and subsequent transmission to Earth.

Two days after Titan encounter a correction maneuver will reduce the apoapse of the Orbiter and adjust its trajectory for the another Titan flyby. The Orbiter will continue on a fom-year satellite tour, using repeated gravity assists from Titan to shape the trajectory to satisfy science objectives. A preliminary tour plan includes shout 60 orbits of Saturn and 33 flybys of Titan at altitudes as low as 950 km. Plans include flybys of the satellites Enceladus, Dione, Rhea anti Iapetus at about 1 000 km distance and more distant flybys of these satellites and of Mimas, slid Tethys. Earth and Sun occultations by Saturn, its rings, and Titan are also planned. End-of-mission will be June 2008. This tour plan is tentative and will be revised

4. SPACECRAFT DESCRIPTION

4.1 Orbiter

Figure 9 (a and b) shows the current spacecraft design. The Orbiter is 6.8 meters long. Its maximum diameter in launch configuration is 4 meters. Total mass of Cassini at launch is approximately 5600 kg, which includes shout 2500 kg of dry mass and 3100 kg of propellants.

The main body of the Orbiter is a stack consisting of lower equipment module, propulsion module, upper equipment module, and high gain antenna. Attached to the stack are the remote sensing pallet and the fields and particles pallet with their science instruments, as well as the Huygens Probe. The two pallets carry most of the science instruments [FIGURE 3-100:4.1-03, "Cassini Remote Sensing Pallet", arid FIGURE 3-100:4.1-(M, "Cassini Fields and Particles Pallet"]. A few instrument assemblies are attached to the upper equipment module. The Orbiter's 12-hay electronics bus is part of the upper equipment module. An 11-m magnetometer boom is mounted on the upper equipment module. A common 32-bit engineering flight processor is utilized by several engineering subsystems and by several science instruments. Thermal control is provided hy reflective multilayer insulating blankets, radiators, reflective and absorptive paints, louvers, shades, radioisotope heater units, and electrical heaters.

The Orbiter is three-axis stabilized. The instruments are mounted to the fixed flame of the spacecraft. In general, the whole spacecraft must be turned to point them in desired directions, though three of the instruments provide their own articulation about one axis. This design was adopted as a cost-saving measure; Cassini's design and operation arc strongly driven by cost. Spacecraft pointing accuracy will be 2 mr or less when the spacecraft is not thrusting or rotating. However, accuracy of pointing with respect to the object being observed is generally limited not by spacecraft pointing accuracy but by navigational uncertainties in the relative positions of the spacecraft and object.

Communication between the Orbiter and Earth is at X-band. The maximum planned data rate from Saturn is 142 kb/s using ground stations with 70-m antennas, 35 kb/s using ground stations with 35-m antennas.

The Orbiter antennas include a 4-m parabolic High Gain Antenna (116A), fixed to the structure. For high telecommunication rates the spacecraft must be oriented to point the HGA at Earth. At other times, especially while the spacecraft is in the inner solar system, the axis of the HGA will be pointed close to the Sun so the antenna will shade most of the spacecraft. During many maneuvers the axis will point in the desired direction of thrust. The HGA must point toward the Huygens Probe when receiving telemetry from the Probe. For observations with remote-sensing instruments, the spacecraft must point these instruments toward the objects of scientific interest, so the HGA cannot then be pointed at Earth. When the HGA cannot be pointed at Earth, telecommunication is limite to low-gain antennas, at very low bit rates.

Ground commands and memory loads go through the radio frequency communication equipment to the Command and Data Subsystem (CDS), which processes them and distributes them to instruments and other subsystems. The CDS also receives data from other subsystems, 1)1 OCCSSCS it, formats it for telemetry, supplies Reed-Solomon encoding, and delivers the telemetry to the radio frequency subsystem for transmission to Earth. A pair of redundant MIL-STD-1553B data buses provide communication with instruments and other subsystems, using packet telemetry. Each user interfaces with the data bus through a standard bus interface unit or a remote engineering unit. The communication rate allocated to science data on the bus is 430 kb/s. Two 1.8-Gb solid-state recorders provide mass storage.

4.2 Huygens Probe

The Huygens Probe system includes both the Probe itself and the Probe Support Equipment, which remains attached to the Orbiter. The Probe Support Equipment incorporates an S-hand receiver to receive telemetry from the Probe after separation, data handling to forward this telemetry to CDS for later transmission to Earth, and an ultla-stable oscillator for RF doppler measurement of Probe velocity relative to the Orbiter.

Probe mass is approximately 340 kg, of which shout 50 kg is science payload. The Probe consists of a blunt-nosed, s])hc~c-cone descent module, encased in a conical front shield, 2,7 m in diameter, which acts as a decelerator during atmospheric entry, and a back cover (Figure 13). Within the descent module, the science instruments and most other Probe equipment are mounted on an instrument platform. The forward dome of the descent module has external spin vanes and there is a swivel on the parachute harness, so the module will spin during descent to provide scan for its camera.

There are accelerometers (range 10^{-4} to 500 m/s^2) to measure both axial deceleration and spin. Redundant frequency modulated continuous wave radar altimeters measure altitude from 2(I km down. Each altimeter transmits 60 mW of RF at 15.4 or 15.8 GHz. Probe command and data management includes 1 Mh of on-board data storage. Telecommunication after the Probe separates from the Orbiter is limited to telemetry from Probe to Orbiter. Data late over the Probe-to-Orbiter link will be 16 kb/s. Total data return from the Probe is expected to be >10 Mh.

S. SCIENCE INSTRUMENTS

S.1 Orbiter

Twelve science instruments are carried by the Orbiter. They are listed in Table 1, which also gives the Principal Investigator or Team Leader for each, as well as mass, power, and output data rate. The science payload mass totals 364 kg.

Most of the instruments contain more than one sensor that provides scientific data. The twelve instruments, as described below, include a total of 27 separate sensors. Each instrument has one or more microprocessors which perform internal control and data handling for that instrument.

5.1.1 Instruments - remote sensing

Six of the Orbiter instruments will measure properties of objects remote from the spacecraft: the imaging Science Subsystem (ISS), Visible and Infrared Mapping Spectrometer (VIMS), Composite Infrared Spectrometer (CIRS), Ultraviolet Imaging Spectrograph (UVIS), Cassini Radar (RADAR), and Radio Science Subsystem (RSS). The first four of these are mounted and co-aligned on a Remote Sensing Pallet and are bore-sighted together. The pallet is in turn mounted on the upper electronics module of the Orbiter.

5.1.1.1 Imaging Science Subsystem (ISS)

The Imaging Science Subsystem consists of a wide-angle camera, a narrow-angle camera, and associated electronics. Each camera includes optics, filter changing mechanism, shutter, and detector head, plus associated electronics. The cameras are used both to acquire scientific data and for optical navigation.

The wide-angle camera has refractive optics, with a focal length of 200 mm, a focal length/diameter ratio (f number) of 3,5, and a 3.5 deg field of view (Figure 14a). Refractive optics were chosen, rather than reflective, primarily to meet mass and cost constraints; these optics were available as spare from the Voyager mission. The narrow-angle camera has Ritchey-Chretien reflective optics, with a 2000-mm focal length, an f number of 10.5, and a 0.35-deg field of view (Figure 14b). Filters are mounted in two rotatable wheels per camera. The wide-angle camera has 18 filters, over the range from 380 to 1100 nm; the narrow-angle camera 24 filters, from 200 to 1100 nm. Two-blade focal plane shutters control exposure. The shortest planned exposure time is 5 ms and the longest 20 min

The sensing element of each camera is a 1024-by-1024-element CCD, coated with phosphor to provide ultraviolet response and cooled to 180 K by a radiator to reduce dark current. Pixel size is 12 µm. The CCDs provide angular resolution of 60 µrad/pixel for the wide-angle camera and 6.0 µrad/pixel for the narrow-angle.

The dynamic range of each camera is about 4000:1, equivalent to 12 bits. Automatic exposure control is available. The data can be reduced to 8 bits/pixel by a lookup table or by reading the 8 least significant bits. A lossless data compressor provides an average compression ratio of 2:1 or greater. There is also a lossy compressor providing average compression ratios as high as 8:1. Editing can be used to sum adjacent pixels or to transmit partial frames. Refs. 8 and 9 give additional information about ISS.

5.1.1.2 Visible and infrared Mapping Spectrometer (VIMS)

The Visible and Infrared Mapping Spectrometer furnishes spectral data over the areas viewed, or, equivalently, maps those areas with lower spatial resolution than ISS but at many wavelengths between 0.35 and 5.1 µm. VIMS will produce information about the surface and atmospheric composition of Saturn and its satellites.

VIMS has separate infrared and visible sensor channels. The IR and visible sensors are mounted on a VIMS optical pallet (Figure 15) which in turn mounts to the spacecraft's Remote Sensing Pallet. Major VIMS assemblies are supplied by the US, Italy and France.

The IR channel covers wavelengths 0.85 to 5.1 µm. Its optics include an f/3.5 Cassegrainian telescope with an aperture of about 230 mm, a collimator, and a diffraction grating. The IR channel produces 0.5x0.5 mrad square pixels. An internal mirror provides two-axis scanning over 64x64 of these pixels, a field 1,9x 1,9 deg, but other scan patterns can be commanded. Radiation is spread in wavelength by the grating and imaged by Cassegrainian camera optics onto a linear detector array of 256 indium antimonide photodiodes, each receiving a separate waveband 16.6 nm wide. The detector is cooled by a radiator to 70 K. The spectrometer operating temperature is 140 K.

The Visible channel produces multispectral images spanning the spectral range from 0.35 to 1.05 µm. It utilizes a Shafer telescope, a holographic grating spectrometer, and a silicon CCD array detector cooled to -30 C by a radiator. One dimension of the array provides spectral separation into 96 wavebands. The other provides linear spati a] separat ion. A single-axis scan mirror scans the array over the scene, perpendicular to the array spatial dimension. The resulting data are 96 2-dimensi onal images of the same region, each in a separate spectral band 7.3 nm wide. The channel generates square 0.5x0.5 mrad pixels to match those of the IR channel

VIMS can record spectra of a single pixel, a line of pixels. or a 2-dimensional array of pixels (an image) with either or both channels[10-12]

S.1.1,3 Composite Infrared Spectrometer (CIRS)

CIRS measures planetary radiation from 10 to 1400 cm'1 (1OOO to 7 μm) in three spectral bands. The CIRS optics assembly includes a telescope, three interferometers, a spectral scan mechanism, and an 80 K cooler. 'l'he telescope is a 50. 8-cm Cassegrainian.

The far infrared interferometer (1 0-600 cm^{-1}, 100010 17 μm) is responsive to both wavelength and polarization. It has an input polarizer, a polarizing beamsplitter, and an output analyzer. Polarizer and analyzer are substrate-mounted wire gr ids. This interferometer has t\vo thermopile detectors, each with a concentrator. Its FOV is 4.3 mrad in diameter. Spectral resolution is 0.5 to 20 cm^{-1}.

The mid-infrared interferometer is a conventional Michelson covering the range 600-1400 cm^{-1} (17 to 7 μm). It employs a Ge lens to focus the interferometer output on two focal planes. One has a 1x10 linear array of photoconductive HgCdTe detectors cove] ing the range 600-1100 cm^{-1}. The other uses a 1x10 linear array of photovoltaic HgCdTe detectors covering 1100-1 400 cm^{-1} The FOV of each detector is about 0.2.7x0.27 mrad. Spectral resolution is 0.5 to 20 cm^{-1}.

The motor-driven scan mechanism moves rc fleeting elements in one dimension to change the path lengths of the three interferometers and hence their pass bands. The third or reference interferometer shares the mid-infrared optical path and provides a servo signal to insure that the motor scans at uniform velocity.

The mid-infrared detector arrays are mounted on an 80 K cooler. Other portions of the optics assembly, including the far infrared detectors, at c cooled to 170 K by a separate radiator. "1'0 reduce heat leakage into tile cold optics assembly, special wires with low thermal conductance are used for its electr ical leads[13].

5.1.1.4 Ultraviolet imaging Spectrograph (UVIS)

The UVIS instrument measures, spectroscopically analyzes, and images ultraviolet emissions at brightness of 0.001 Rayleigh to several thousand Rayleighs. UVIS is a t\vo channel spectrograph (far and extreme ultraviolet), and includes a hydrogen-deuterium absorption cell and a high-speed photometer.

Each of the two spectrographic channels utilizes a reflecting telescope, a concave grating spectrometer, and an imaging, pulse-counting detector. The telescope primarys are off-axis parabolic sections with a focal length of 100 mm, a 2.2x30 mm aperture, anti a FOV of 3.67x0.34 deg. The spectrometers use aberration-corrected toroidal gratings to focus the spectr um onto an imaging microchannel plait detector (MCI'). The far ultraviolet channel has a wavelength range is 115 to 190 nm. The range of the extreme ultraviolet channel is 55 to 115 nm. Each channel has three selectable entrance slits providing spectral resolution down to 0.21-0.24 nm. For solar occultation observations, the extreme ultraviolet channel includes a mechanism that allows sunlight to enter when the sun is 20 deg off the telescope axis.

The high-speed photometer measures undisper sed (zero-order) light from its own parabolic mirror with a photomultiplier tube detector, The wavelength range for this photometer channel is 115 to 185 nm; the FOV is 0.34x0.34 deg. Time resolution is 2 ms.

The hydrogen-deuterium absorption cell channel is a photometer which measures hydrogen and deuterium concentrations. incoming light passes through an objective lens and then through t\vo resonance absorption cells, onc filled with hydrogen and the other with deuterium. A tungsten filament in each cell dissociates a fraction of the molecular gas, allowing the hydrogen/deuterium spectrum near the resonance lines to be measured to high resolution by varying the filament temperature. A third cell, filled with oxygen, selectively transmits Lyman-alpha lines while attenuating nearby wavelengths Photons that have passed through all three cells are detected by a channel electron multiplier[14]

s.1.1.S Cassini Radar (RADAR)

The Cassini radar is designed for observation of the surface of Titan during close flybys of that satellite. It operates at Ku-band. The radar includes an RF subsystem, digital subsystem, and power conditioner. The radar utilizes the Orbiter's high gain antenna. It can be switched from onc to another of five Ku-band feeds (microstrip arrays), offset from the focal point of the high gain antenna, which generate five side-lookil)g beams. A frequency-selective subreflector transmits the radar Ku frequency but reflects the X-hind communications frequency.

The instrument has three operating modes: synthetic aperture imaging, altimetry, and radiometry. Its peak RF output is 63 W. Pulse rate for imaging is 2-4 kHz and pulse length 100-500 μs. For low resikution altimetry, the pulse rate is 1-3 kHz and the pulse length 500 μs, for high resolution altimetry 4,7-5.6 kHz and 150 μs. For radiometry measurements, the radar dots not transmit but it receives blackbody radiation from the surface of Titan, using integration times of 0.01 to 5 s.

Radar data are not processed aboard the spacecraft. They are buffered in the radar electronics and forwarded to the Orbiter command and data handling subsystem as the bus data rate permits.

The radar will operate at altitudes below 22,500 km. At altitudes between 22500 and 9,000 km, it will multiplex between altimetry and radiometry to obtain low-resolution global maps of Titan's surface brightness temperature and surface backscatter characteristics. During these periods the Orbiter will scan the surface with its high-gain antenna. At altitudes between 9,000 and 4,000 km, the instrument will multiplex between altimetry and radiometry, collecting high-resolution altimetric and surface emissivity measurements along the sub-orbital track, while the spacecraft points the antenna beams toward the nadir. Below 4000 km, RADAR will multiplex imaging and radiometry. During this operation the spacecraft will point the radar antenna beams at a range of angles away from nadir on either the left or the right side of the sub-orbital track, and surface images and emissivity measurements will be collected in alternation. The radar can acquire high- m low-resolution images by using different bandwidths and coherent data window sizes. Low-resolution imagery will be obtained at altitudes between 4,000 and 1,600 km and high-resolution imagery below 1,600 km. imaging resolution of the hardware is down to 540x350 m. Radiometry temperature rsolution is <0.35 K. (Refs. 15-16)

5.1.1.6 Radio Science Subsystem (RSS)

Orbiter Radio Science measurements will provide data on the atmospheres and ionospheres of Saturn and Titan, on the rings, and on the gravity fields and ephemerides of Saturn and its satellites. During cruise the instrumentation will be used to search for gravitational waves, in a general relativity measurement, and to obtain electron densities of the solar corona.

The experiment employs both the X-band communications link of the spacecraft Radio Frequency Subsystem (RFS) and the Ka - and S-hand capabilities of the Radio Frequency Instrument Subsystem (RFIS). The RFS includea an X-band transponder, which contains a receiver and an exciter, and an X-band travelling-wave tube power amplifier, providing 10.6 W radio frequency output, The RFS also includes an ultra-stable oscillator for the Radio Science experiment.

The RFIS contains an S-band transmitter and a suite of Ka-band equipment: a translator, an exciter which generates a downlink signal, and a 'TWT' amplifier. The S-Band transmitter receives a signal from the USO, multiplies its frequency, amplifies it to 10 W, and supplies the resultant signal at 2298 MHz to the high gain antenna The Ka-exciter generates a 32 GHz signal from the USO output. The Ka-band phase-lock loop translator receives the 34 GHz uplink carrier from the high gain antenna and translates the carrier by a factor of

14/1 5 for retransmission to Earth. Ka-band amplifier output is 10 W. Figure 20 is a block diagram of the Radio Science equipment.

The high gain antenna has feeds for X, S, and Ka-bands. Links are with 34- and 70-m antenna Earth stations of the Deep Space Net.

The equipment mentioned provides two-way links at X and Ka-band plus downlink at S-band. Downlinks with accurately known frequency, originating from the ultrastable oscillator, can be transmitted by the X-band TWT amplifier, the Ka-band exciter and amplifier, and the S-band transmitter. Two-way coherent signals are provided by X-band uplink to the transponder and by Ka-band uplink to the translator, in conjunction with the X and Ka downlinks mentioned. Capabilities include one- and two-way doppler, differential one-way ranging, and two-way ranging.

Frequency stability of transmissions (Δf/f), set by the ultrastable oscillator, is better than 1×10^{-13} for integration times of 10 to 10,000 s. Allan deviation of Ka-band transmissions is $<1 \times 10^{-15}$. Two-way ranging provides an accuracy Of 20 to 30 ns (6 to 9 m).

For measurements of mass and mass distribution, use will be made of the spacecraft's telecommunications and imaging equipment, particularly the X-band transponder, the high-gain antenna, and the wide-angle camera. The phase and phase shift of 2-way signals are used for detection of gravitational waves with periods between 1000 and 10,000 seconds and for the measurement of gravity fields[17].

Various combinations of the available capabilities are used for different types of measurements. These include:

Gravitational waves (period 1,000 to 10,000 s):	
	2 or 3-way doppler: X up X down, X up Ka down, Ka up Ka down
General relativity:	2-way doppler: x up x (low]), X up Ka down, Ka up Ka down, X up S down
Solar corona:	2-way range and doppler: X up X down, X up Ka down, Ka up Ka down, X up S down
Mass and gravity fields:	2-way doppler and range: X up X down, X up Ka down, Ka up Ka down, X up S down
Ephemerides:	2-way doppler and range: X up X down, X up Ka down, Ka up Ka down; Wide Angle Camera
Rings, atmospheres and ionospheres:	1-way doppler: X, Ka> S

S.1.2 Instruments - Fields, Particles, and Waves

Six instruments that observe fields, particles, and plasma waves are the Dual Technique Magnetometer (MA(i), Radio and Plasma Wave Science (RPWS), Cassini Plasma Spectrometer (CAPS), Magnetospheric imaging Instrument [M IMI), Cosmic Dust Analyzer (0CDA), and Ion and Neutral Mass Spectrometer (I NM S).

S.1.2.1 Dual Technique Magnetometer (MAG)

The Dual Technique Magnetometer measures the magnetic field vector. It consists of a 3-axis Flux Gate Magnetometer and a Helium Magnetometer The Vector/Scalar Helium Magnetometer measures the magnitude of the magnetic field or, alternatively, its three orthogonal components. The magnetometer boom supports the helium magnetometer at its outboard end and the flux-gate near its midpoint (Figure 8b). Magnetometer electronics are in a spacecraft hay.

Operation of the helium magnetometer is based on field-cicimndent light absorption (the Zeeman effect) and optical pumping. RF excitation of a lamp filled with helium, at low pressure, generates infrared light, which passes through a polarizer and a absorption cell to a silicon detector (Figure 24 b), Helium in the absorption cell is excited by RF discharge to produce metastable atoms. Net optical pumping in the cell is maximum when no magnetic field is present; the presence of a field reduces optical pumping and result in increased absorption For vector field measurements, the absorption is modulated by a rotating sweep field generated by triaxial Helmholtz coils. Detector output components at the sweep frequency are nulled by feedback through the Helmholtz coils, providing a measurement of all three components of the ambient field vector. Scalar field measurements utilize a separate coil whose output is frequency modulated. A component of the detector output signal is related to the Larmor frequency, which is directly proportional to the magnetic field

The flux gate magnetometer has three identical sensors (Figure 24a), oriented orthogonally to each other. in each, a permeable ring core is wound with a coil, operating at 18 kHz, which drives the core to salutation. A pickup coil surrounds the core. The presence of an ambient field component parallel to the coil axis causes the core saturation to become unsymmetrical and induces a second harmonic in the pickup coil that is proportional to the ambient field component.

The use of two separate magnetometers at different locations aids in distinguishing the ambient magnetic field from that produced by the spacecraft. The helium magnetometer has full scale flux ranges of 32 and 256 nT in vector mode, 256 to 16,000 nT in scalar mode. It provides highest sensitivity at frequencies up to 1 or 2 Hz; its frequency range is up to 1O Hz. The flux gate magnetometer has flux ranges of 40 to 44,000 nT. It is most sensitive at 1 to 20 Hz and responds to frequencies up 10 100 Hz. (Ref. 18)

S.1 .2.2 Radio and Plasma Wave Science (RPWS)

The Radio and Plasma Wave Science instrument will measure AC electric and magnetic fields in the plasma of the interplanetary medium and Saturn's magnetosphere, and also electron density and temperature. Sensors include three electric antenna elements, a 3-axis magnetic search coil assembly, and a Langmuir probe,

Two of the antenna elements are configured as a dipole, the other is a monopole. They are mounted on the upper equipment module of the Orbiter (Fig. ???). Each antenna is a collapsible tohc which is rolled up for launch and subsequently released to Self-extend to its 10-m length

The magnetic search coil assembly includes three orthogonal coils about 25 cm in diameter and 260 cm long, each with a high-permeability core, a main winding, and a feedback winding. The Langmuir probe, which measures electron density and temperature, is a metallic sphere 5 cm in diameter. The magnetic search coils are mounted on a small platform attached to a sopport for the High Gain Antenna; the Langmuir probe is attached to that platform by a 1-meter deployable boom.

Signals from the sensors go to high- and medium-frequency receivers, a wide-band receiver, and a 5-channel waveform receiver. These receivers provide low and high time and frequency resolution measurements. FIGURE 4-2073:-01 is a functional block diagram of RPWS.

Ranges are 0.1 Hz to 16 MHz for electric fields, 0.1 Hz to 12.6 kHz for magnetic fields, electron densities of 5 to 10,000" c/cm^3, and electron temperatures equivalent to 0.1 to 4 eV. Sensitivity to electric fields at 1kHz is 0.4 μV narrowband, 100 $nV/Hz^{-1/2}$ wideband; at 20 kHz, 0.1 μV narrowband, 5 $nV/Hz^{-1/2}$ wideband. Sensitivity to magnetic fields at 1kHz is 0.03 pT narrowband, 0,007 $pT/Hz^{-1/2}$ wideband. Dynamic range is >90 dB.

RPWS also has a sounder mode. Square wave pulses 1 to 320 μs long are generated and transmitted by the antenna to stimulate plasma resonances. The received signals are analyzed to give electron densities[19]

5.1.2.3 Cassini Plasma Spectrometer (CAPS)

The Cassini Plasma Spectrometer measures composition, density, flow velocity, and temperature of ions and electrons in Saturn's magnetosphere, using three sensors: an Ion Mass Spectrometer, an Ion Beam Spectrometer, and an Electron Spectrome cr. A motor-drivel) actuator rotates the sensor package to provide 200 deg scanning in azimuth about the z-axis of the Orbiter.

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The Electron Spectrometer (ELS) uses a curved-plate electrostatic analyzer and MCP detectors for electron energy measurements. ELS energy range is 0.7 to 30,000 ev with a resolution (ΔE/E) of 0.17. The sensor's FOV is 5x160 deg and angular resolution 5x20 deg.

The Ion Beam Spectrometer (IBS} uses a curved-plate electrostatic analyzer and channel electron multiplier detectors to determine energy/charge ratios. The energy range of the IBS is 1 eV to 50 keV and energy resolution 0.0125. Field of view is 1.5x180 deg and angular resol ution 1 .5x1.5 deg.

The Ion Mass Spectrometer (IMS) provides data on both energies/charge and mass/charge ratios. A curved-plate electrostatic analyzer provides energy/charge separation (Figure 23a). The ions are then accelerated electrostatically and strike a set of thin carbon foils. This produces secondary electrons and breaks up some of the molecular ions. Secondary electrons strike a MCP electrostatic analyzer in which the electric field increases linearly along the analyzer length. Positive ions with less than 15 kev kinetic energy are deflected back to the entrance end Of the analyzer where they strike the MCP detector. Their time of flight indicates their mass/charge ratio. Positive ions with higher energy, and neutral s, strike another MCP at the opposite end. Fragments resulting from breakup of molecular ions supply information on their composition.

The mass range of the IMS is 1 to 60 amu; its mass resolution (Δm/m) is (), 2 to 0.03. The energy range is 1 eV to 50 kev, with a resolution of 0.17. Field of view is 12x160 deg, angular resolution 12 x20 deg.

Ref 20 gives further information about CAPS.

S,1.2.4 **Magnetospheric Imaging Instrument (MIMI)**

The Magnetospheric Imaging Instrument will provide images of the plasma surrounding Saturn and determine ion charge and composition. Like CAPS, it has three sensors. One of these, the Low Energy Magnetospheric Measurements System (LEMMS), has eight detectors to provide directional and energy information on electrons at 15 kev to 10.5 Mev, protons at 15 to 130 Mev, and other ions at 20 keV to 10.5 MeV/nucleon. The LEMMS head is double-ended, with oppositely directed 15 deg and 45 deg conical FOV. LEMMS is mounted on a platform which permits continuous rotation of the head through 360 deg on an axis perpendicular to the Orbiter High Gain Antenna axis and to the LEMMS telescope axis.

Another sensor, the Charge-Energy-Mass Spectrometer (CHEMS) measures charge and composition of ions at IO to 265 keV/e with an electrostatic analyzer and a time-of-fright mass spectrometer. Its mass/charge range is 1 to 60 amu/e (elements H-Fe) and molecular ions mass range 2 to 120 amu. Energy resolution (Δ(E/Q)/(E/Q)) is 0.05 and mass resolution (Δm/m) is 0.11. The CHEMS head has a ±80 deg by 6 deg FOV. The minimum measureable flux is 1 ion/(cm^2 sr keV/e) and the dynamic range is 10^8.

The third MIMI sensor, the Ion and Neutral Camera (INCA), makes two different types of measurements. It determines the 3D distribution function, velocity spectra, and rough composition of ions and neutrals with energies from 10 keV to about 8 MeV/nucleon, and it provides remote images of the energetic neutral emission from the hot plasmas of Saturn's magnetosphere, measuring the composition and velocity spectra of those energetic neutrals for each image pixel. INCA is a time-of-fright camera with collimator slits, an entrance foil, and microch annel plate detectors. Though MIMI is listed as a Fields and Particles instrument, INCA might also be classified as a remote sensor, and it is bore-sighted with the spacecraft remote sensing instruments. INCA has a ±60 deg by ±45 deg FOV and an angular resolution of about 2x2 deg. Its velocity resolution is 5(I km/s and its dynamic range 10^7.

The different MIMI sensors share common electronics, and provide complementary measurements of energetic plasma distribution, composition, and energy spectrum, and the interaction of that plasma with the extended atmosphere and satellites of Saturn.

5.1.2.S Cosmic Dust Analyzer (CDA)

The Cosmic Dust Analyzer measures flux, velocity, charge, mass, and composition of dust and ice particles in the mass range 10^{-16} to 10^{-6} g. It has two types Of sensors, High Rate Detectors and a Dust Analyzer. The two High Rate Detectors use depolarization of polyvinylidene fluoride film (PVDF) by impacting particles to count impacts up to 10,000/s. These are intended primarily for measurements in Saturn's rings. One of the High Rate Detectors has a film 28 µm thick with an area of 50 cm^2. The other has film 6 µm thick and an area of 10 cm^2.

The Dust Analyzer uses impact ionization), time-of-flight measurements, ion collectors, and charge-sensitive amplifiers to obtain data at rates up to 1 particle/s. It measures the electric charge carried by dust particles, the flight direction and impact speed, mass, and chemical composition. The Dust Analyzer has two pick up grids at its entrance to measure particle charge. An impact ionization target, at O V potential, collects electrons of the impact plasma. A chemical analyzer target, at +1000 V, with a grounded grid in front of it, accelerates the positive ions. Ions reaching this grid signal the start time for the time-of-flight mass spectrometer. A negatively biased grid collects the ions. An electron multiplier amplifies the signal caused by ions that penetrate the ion collector grid. ~ha~gc-sensitive amplifiers and a logarithmic amplifier measure the charge signals over a range of 10^{-16} to 10^{-12} Coulomb The mass resolution of the ion spectrum (m/Δm) is approximately 50. The Dust Analyzer detects particles impacting at 1 to 100 km/s.

An articulation mechanism permits the instrument to be rotated to several positions, relative to the Orbiter body.

5,1.2.6 Ion and Neutral Mass Spectrometer (INMS)

The Ion and Neutral Mass Spectrometer will determine the chemical, elemental, and isotopic composition of the gaseous and volatile components of the neutral particles and the low energy ions in Titan's atmosphere and ionosphere, Saturn's magnetosphere, and the ring environment. It will also determine the gas velocity.

Principal subsystems of INMS are two ion sources, an electrostatic quadrupole deflector, a quadrupole mass analyzer, and a detector

Ions of the plasma are analyzed as they enter, but neutrals must first be ionized within the instrument. In the open ion source, incoming neutral molecules and atoms are collimated into a beam, then ionized by impact of electrons from an electron gun. This source is used primarily for components that might react if allowed to strike instrument surfaces. The closed ion source uses ram density enhancement to increase sensitivity and accuracy for the more inert atomic and molecular species. Ram enhancement is achieved by limiting the gas conductance from an enclosed antechamber while maintaining a high flux into the chamber. The maximum density enhancement will be x45 at mass 28 amu for a 5.4 km/sec spacecraft velocity. In both ion sources, the neutrals are ionized by electron impact.

Thermal and suprathermal ions of the plasma surrounding the spacecraft enter INMS through the collimator of the open source. Ions emerging from the ion sources are directed into the mass analyzer by a 90 deg quadrupole deflector, The deflector also functions as an electrostatic energy filter in the open mode operation, providing an indication of the energy distribution of ions or neutrals entering the open source.

The mass analyzer is a quadrupole mass filter. As ions exit the analyzer they go into an ion detector (secondary electron multiplier), which feeds a pulse counter.

The field-of-view of the open source for neutral species is a 16 deg conical full angle; the closed source has a hemispherical FOV. The mass range of INMS is 1 to 8 and 12 to 99 amu. The density range for neutral gas is 10 to 10^{12} molecules/cm^3. Sensitivity for neutrals is 2.5×10^{-3} counts per molecule/cm^3-s, for ions 1×10^{-3} counts per ion/cm^3-s.

5.2 Probe

The six instruments on the Huygens Probe are the Huygens Atmospheric Structure Instrument (HASI), Aerosol Collector Pyrolyser (ACP), Gas Chromatograph / Mass Spectrometer (GCMS), Descent Imager \ Spectral Radiometer (DISR), Doppler Wind Experiment (DWE), and Surface Science Package (SSP). They include a total of 39 sensors

5.2.1 Huygens Atmospheric Structure Instrument (HASI)

The Huygens Atmospheric Structure Instrument includes a variety of sensors. Atmospheric pressure is measured by deflection of a diaphragm. This sensor has a resolution of ±0.04% or ±0.005 mbar. A Pitot tube inlet, on a stub extending beyond the Probe descent module, brings the pressure to the sensor Four platinum resistance thermometers, also mounted on the stub, measure atmospheric temperature, with a resolution better than 0.02 K below 110 K and **0.07** K at higher temperatures.

For determination of atmospheric density, a servo accelerometer measures acceleration along the spin axis over switchable full-scale ranges Of 2 mg to 18.5 g, with a resolution 0.05% of full scale. Three piezoresistive accelerometers measure acceleration along all three axes of the Probe, over a range of ±20 g with a resolution of ±50 mg. A microphone senses acoustic noise, at 0-6 kHz, from thunder, precipitation, and turbulence.

A permittivity and wave analyzer includes an array of six electrodes, mounted on two deployable booms. One pair of electrodes transmits signals at 43 to 5500 Hz which are received by another pair. Measurements of the magnitude and phase of the received signal give the permittivity and electronic conductivity of the atmosphere and surface,. Signals of natural origin, at frequencies up to 10 kHz, are also received. The voltage detected between two other electrodes (in the absence of transmission) gives the DC eletric field. When these electrodes are charged to ±5 V and isolated, the time constant for relaxation of the voltage indicates the ionic conductivity of the atmosphere.

HASI also processes the IF signal from the Probe's radar altimeter to obtain information on surface topography, structure, roughness, and electrical properties.

5.2.2 Aerosol Collector Pyrolyser (ACP)

The Aerosol Collector Pyrolyser will collect samples of the aerosols in Titan's atmosphere using a deployable sampling device extended beyond the boundary layer of the Probe. Samples will be obtained at two altitude ranges. The first sample, at altitudes down to 30 km, will be obtained primarily by direct impact on a cold filter target, the second sample, at about 20 km, by pumping atmosphere through the filter.

After each collection the filter, expected to contain about 30 µg of aerosol, will be transferred to an oven and heated to three successively higher temperatures, up to about 650 C, to vaporize and pyrolyze the collected material. The effluent produced at each temperature will be swept up by nitrogen earlier gas and transferred to the GCMS for analysis.

One ACP module contains the sampling device and oven, a second the pump and exhaust tube, a third the carrier gas reservoir, pressure regulator, and valving, and a fourth the lines and valving for transfer to the Gas Chromatograph / Mass Spectrometer (GCMS) for analysis. 21)

5.2.3 Gas Chromatography / Mass Spectrometer (GCMS)

The Gas Chromatograph / Mass Spectrometer will provide quantitative analysis, inducting isotopic analysis, of the atmosphere. Atmospheric samples are transferred into the instrument by dynamic pressure as the Probe descends through the atmosphere. Samples obtained at high altitudes can be stored for later analysis.

The GCMS uses an inlet port near the stagnation point at the apex of the Probe, and an outlet port at a low pressure point. The instrument contains three chromatographic columns One column has an absorber chosen to separate CO, N_2, and other permanent gases, Another has an absorber that will separate nitriles and other highly polar compounds. The third is to separate hydrocarbons up to C_8

The mass spectrometer serves as detector for the gas chromatograph. It will .s1s0 analyze unseparated atmospheric samples and those provided by the Aerosol Collector Pyrolyser. It has individual inlets for each of these, and a separate ion source for each gas chromatograph column and each other inlet For gas entering directly from the atmosphere, two pressure-reducing leaks can be valved in to reduce pressure to the operating range of the mass spectrometer ion source. A getter pump and a sputter ion pump maintain this operating pressure range, Ionization is by electron impact, ion separation by a quadrupole mass analyzer, ion detection by a secondary electron multiplier. The mass range is 2 to 14(, amu, detector threshold mixing ratio 1x 10"]* (at S/N= 1), and dynamic range 10^8

Portions of the Probe GCMS and the Orbiter INMS instruments share identical designs

S.2,4 **Descent Imager \ Spectral Radiometer (1)1S1<)**

The Descent Imager \ Spectral Radiometer will obtain data on the thermal balance of the atmosphere and surface of Titan, clouds and cloud particles, concentrations of argon and methane, whether the local surface is solid or liquid, and, if solid, its topography. DISR contains thirteen sensors, operating at wavelengths of 350-1700 nm. These include three framing imagers, looking downward and horizontally, a spectrometer dispersing light from two sets of optics looking downward and upward, and four solar aureole radiometers. All of these output light via fiber optics bundles to different areas of a single 256x520 CCD pixel array. The spectral range of the imagers is 660 to 1000 nm; their pixel resolution is 0.06 to 0.20 deg. The spectrometers' range is 480 to 960 nm, with a pixel spectral resolution of 2.4 nm. The aureole radiometers operate at 475-525 and ') 1 0-960 nm, with t\vo different polarizations, and have 1 deg pixel resolution.

Separate downward- and upward-looking optics are linked by fiber optics bundles to an IR grating spectrometer. The IR optics include a shutter. The IR detectors are linear InGaAs photodiode arrays, which output through wire connections to a CCD. Their spectral range is 870 to 1700 nm, spectral resolution 6.3 nm.

There are also t\vo violet photometers, looking downward and upward. Their detectors are silicon photodiodes Their bandwidth is 350 to 470 μm; each records as a single pixel.

To provide reference and timing for the other measurements, DISR uses a sun sensor with a three-slit reticle and a silicon photo diode to measure solar azimuth and zenith angle relative to the rotating Probe.

1)ISR contains a lamp to provide additional illumination of the surface of Titan for measurement of spectral reflectance in the methane absorption bands.

5.2.5 Doppler Wind Experiment (I)\\'It)

The I)oppler Wind Experiment measures the height profile of zonal wind and its turbulence. It utilizes an ultrastable oscillator (USO) on the Probe and another on the Orbiter. The output frequency of each USO is set by a rubidium oscillator. The I'robe USO sets the carrier frequency of onc of the S-band transmitters on the Probe. The frequency received by the Orbiter for this channel is recorded and stored for transmission to Earth. '1'here it is compared with that of the (h biter USO, recorded at the same time, to determine the Doppler velocity between Probe and Orbiter. Modulation of the 1)oppler frequency will provide data on the Probe spin rate, spin phase. and parachute swing.

The long-term frequency stability of each USO (Af/f), over the Probe descent time of 2 to 2.5 hours, is better than $2x10^{-10}$. The sholt-term stability (Allan deviation), over 100 s, is $1x10^{-12}$. Wind will be measured to a precision of 1 m/s. Vertical resolution of wind shear will vary with altitude, from 1800 m at 130 km altitude to about 20 m at the surface[22].

S.2.6 Surface Science Package (SSP)

The Surface Science Package contains sensors to determine the physical properties and composition of the surface. Among them are two piezoelectric impact accelerometers, one within the descent module, one on a spear, which will indicate whether the surface is solid or liquid. There are two sensors (liquid-filled tubes with electrodes) to measure tilt about two axes after landing. A group of platinum resistance wires, through two of which a heating current can be passed, will measure temperature and thermal conductivity of the surface and lower atmosphere and the heat capacity of the surface material. A pair of piezoelectric transducers, one transmitting and the other receiving a 220 kHz acoustic signal, will measure acoustic velocity. Another transducer, pointed downward and operating at 20 kHz, will conduct acoustic sounding of liquid depth, if the Probe lands in liquid.

An opening at the bottom of the Probe body, with a vent extending upward along the Probe axis, will admit liquid. This will fill the space between a pair of electrodes. The capacitance between the electrodes gives the dielectric constant of the liquid; the resistance gives the electrical conductivity. A float, with electrical position sensors, will determine the liquid's density. A sensor to measure refractive index of the liquid has LED light sources, a prism with a curved surface, and a lineal photodiode detector array. The position of the light/dark transition on the detector array indicates the refractive index.

6. OPERATIONS

6.1 Orbiter

Power available on the Orbiter is not sufficient to operate all instruments and engineering subsystems simultaneously. orbiter operations are therefore divided into a number of operational modes. In each mode power is allocated among the instruments and engine-cling subsystems as appropriate for the operation. Some of the modes are for engineering operations, some for gathering of science data. For example, during much of the orbital tour of Saturn, 16 hours in a Remote Sensing Mode will alternate with 8 hours in a Fields, Particles, Waves, and Downlink Mode, In the Remote Sensing Mode, most of the remote sensing instruments will be acquiring data; many of the fields and particles instruments will not. In the Fields and Particles Mode, the reverse will be true, Other science modes will be used during satellite flybys, occultations, cruise to Saturn, etc. Instruments not gathering data will generally not be turned off during the orbital tour, but rather will be left in a low-power "Sleep" state. This is to reduce on-off thermal cycling, keep high voltages on to avoid a need to turn voltage up slowly each time, and preserving RAM to avoid the need to reload it each time.

The operational modes differ in other characteristics than power. In Remote Sensing, for example, the Orbiter is oriented to point remote sensing instruments toward their objects of interest. This means that the High Gain Antenna cannot be pointed toward Earth, so telemetry is stored in the solid-state recorders for transmission later. in the Fields, Particles, Waves, and Downlink Mode the High Gain Antenna is pointed to Earth, permitting transmission of stored and real-time telemetry, and the Orbiter is rolled about the Antenna axis at 0.26 deg/s to provide scanning about an axis additional to the articulation axes of some instruments.

The bit rate available on the Command and Data Subsystem data bus is not high enough to permit all instruments to output telemetry simultaneously at their maximum rates. The Orbiter is switched among a number of different telemetry modes in which the available bit rate is allocated differently among the instruments.

Some of the instruments adjust their operating state or parameters depending on the activities of the spacecraft or other instruments and what environment the Orbiter is encountering. When these other conditions arc predictable from the command sequence, commands for the instruments arc ordinarily set accordingly. When they are not predictable, or if it is simpler to handle the adjustment on board, the Command and Data System relays information from the subsystem providing the information to the instruments that need it. Specifically, information on spacecraft attitude and its rate of change, warnings of thruster firings, measurements of the magnetic field vector, and notices of operation of the sounder and Langmuir probe in the Radio and Plasma Wave Science instrument, are broadcast for use by the Cassini Plasma Spectrometer, Cosmic Dust Analyzer, and Magnetospheric Imaging Instrument.

6.2 Probe

There is no radio transmission link to the Huygens Probe after it separates from the Orbiter; it is wholely autonomous. The Huygens Atmospheric Structure Instrument is turned on to acquire data during entry. The other instruments are turned on in a pre-programmed sequence after tbe Probe cover is released. The Probe goes through five successive power configurations, in which the available power is allocated differently among the various instruments. Operation is controlled by timers, acceleration sensors, altimeters, and sun sensor, The Probe's Command and Data Management Subsystem broadcasts altitude and spin rate data to the instruments. Data collection goes through three successive steps in which the available data rate is allocated differently among the instruments[7].

7. SUMMARY

The Cassini mission will bring eighteen scientific instruments to Saturn. After the spacecraft is inserted into Saturn orbit, it will separate into a Saturn Orbiter and an atmospheric probe, called Huygens, which will descend to the surface of Titan. The Orbiter will orbit the planet for four years, with close flybys of Enceladus, Dione, Rhea and Iapetus, and multiple close flybys of Titan.

The Orbiter is three-axis stabilized.. Its twelve science instruments are body-mounted; tbc spacecraft must be turned to point them toward objects of interest, Optical instruments provide imagery and spectrometry at wavelengths from 55 nm to 1 mm A radar instrument supplies synthetic aperture imaging, altimetry, and microwave radiometry. S-, X-, and Ka-band link measurements between Orbiter and Earth will provide information about intervening material and gravity fields. Field and particle instruments will measure magnetic and electric fields, plasma properties, and the flux and properties of dust and ice particles. Maximum downlink rate from Saturn is 142 kb/s.

The Probe is spin-stabilized. A heat shield decelerates it and protects it from heat during entry to Titan's atmosphere. Parachutes then slow its descent to the surface. The Probe carries six instruments. These include sensors to determine atmospheric physical properties and chemical composition, Optical sensors will observe temperatures and thermal balance and obtain images of Titan's atmosphere and surface. Doppler measurements over the radio link from Probe to Orbiter will provide wind profiles. Surface sensors are carried to measure impact acceleration, thermal properties of the surface material and, if the surface is liquid, its density, refl-active index, electrical properties, and acoustic velocity. The Probe returns its data via an S-band link to the Orbiter.

8. ACKNOWLEDGMENTS

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Table 1 Cassini Orbiter Investigations / Instruments

Investigation		Principal Investigator (PI) or Instrument Manager (IM)	Mass kg	Typical Peak Power W	Max. Data Rate kb/s
Cassini Plasma Spectrometer	(CAPS)	David Young (PI) Southwest Research Institute	21.4	21.0	16.0
Cosmic Dust Analyzer	(CDA)	Eberhard Grün (PI), Max-Planck Institut fur Kernphysik	16.7	19.5	0.5
Composite Infrared Spectrometer	(CIRS)	Virgil Kunde (PI). Goddard Space Flight Center	44.3	32.5	6.0
Ion and Neutral Mass Spectrometer	(INMS)	Jack Richards (IM), Goddard Space Flight Center	13.0	31.0	1.5
Imaging Science Subsystem	(ISS)	Thomas Livermore / William Harris (IM) Jet Propulsion Laboratory	61.1	70.8	366.0
Dual Technique Magnetometer	(MAG)	David Southwood (PI), Imperial College	9.8	13.0	2.0
Magnetospheric Imaging Instrument	(MIMI)	Stamatios Krimigis (PI), Applied Physics Laboratory, Johns Hopkins University	[illegible]8.5	26.1	[illegible].0
Cassini Radar	(RADAR)	Young Park / Mimi Paller (IM), Jet Propulsion Laboratory	56.7	1[illegible]0.0	365.0
Radio and Plasma Wave Science	(RPWS)	Donald Gurnett (PI), University of Iowa	39.0	18.3	370.0
Radio Science	(RS)	Carole Hamilton (IM), Jet Propulsion Laboratory	15.5	89.0	0.0
Ultraviolet Imaging Spectrograph	(UVIS)	Larry Esposito (PI). University of Colorado	16.0	14.0	31.0
Visual and Infrared Spectrometer	(VIMS)	David Juergens (IM), Jet Propulsion Laboratory	40.1	29.2	183.0
TOTAL			361.9	---[b]	---[c]

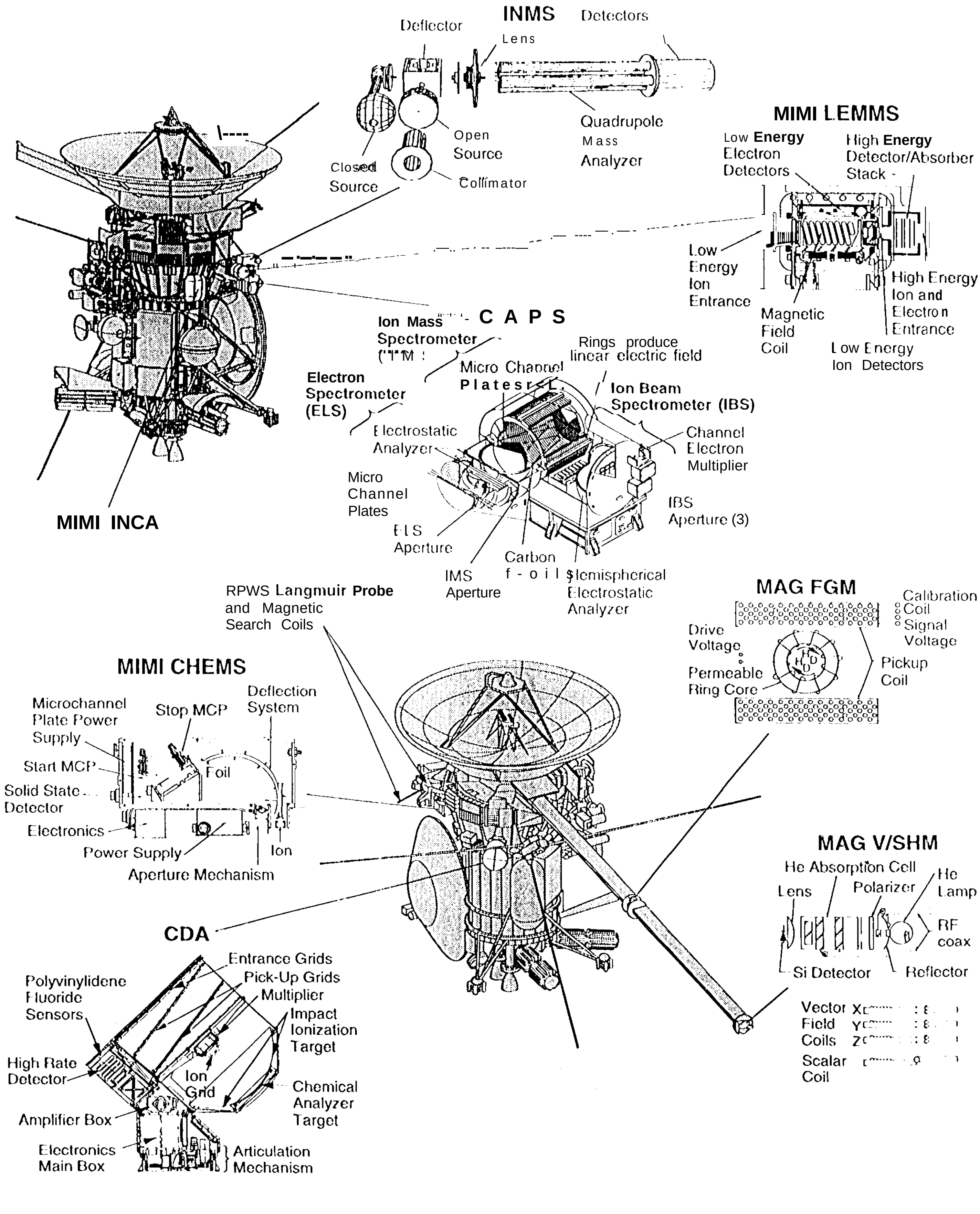
[a] The five instruments for which an Instrument Manager (IM) is listed are facility instruments
[b] Instruments are not at peak power at the same time
[c] Instrument are not at maximum data rates at the same time

Table 2 Huygens Probe Investigations/Instsruments

Investigation	Principal Investegator	Mass, kg	Peak Power W	Energy Whr	Peak Data Rate b/s
Aerosol Collector Pyrolyser (ACP)	Guy Israel Service d' Aeronomie Verrieres0le Buisson	6.7	13.3/ 71.5*	69.8	128
Descent Imager/Spectral Radiometer (DISR)	Martin Tomasko University of Arizona	8.5	39.8	45.7	4800
Doppler Wind Experiment (DWE)	Michael Bird Universitat Bonn	2.1	18.6	25	10
Gas Chromatograph/Mass Spectrometer (GCMS)	Hasso Niemann Goddard Space Flight Center	19.5	44.5	110	960
Huygens Atmospheric Structure Instrument (HASI)	Marcello Fulchignoni Universita di Roma	6.7	22.5	41	895
TOTAL		47.7		317.5	6912+

*ACP is allocated two power lines.

+ Instrument data rates do not peak at same time



Jaffe/Alexander Fig 17

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